Report for 1976 - Part 1

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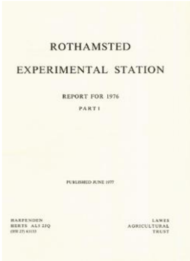
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EXPERIMENTAL STATION
REPORT FOR 1976
PART 1

Plant Pathology Department

E. Lester

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Introduction

This year has seen the third successive exceptional season, each more exceptional than the last. The autumn and spring augured well but the extreme drought of the summer was not effectively broken until the end of the first week of September. Subsequently the weather remained mainly wet, with severe frosts before the end of the year. These conditions generally affected yields more than did disease, spring-sown cereals and potatoes being most seriously affected. Once again potatoes had an especially difficult year, with low yields and all the phenomena of 'second growth' rendering cv. King Edward all but useless (p. 271). For the second successive year this variety grown to supply seed for Rothamsted experiments has had to be rejected because of exceptional spread of virus, a result in part of the resistance of the aphid population to organo-phosphorus insecticides (p. 276). Investigations on bacterial soft rot suffered from the dry season, as might

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have been expected, no spread in soil being detected throughout the season until the onset of rain in September (p. 271).

The drought offered an unusual opportunity to study aspects of the spread of barley leaf blotch, which showed that spread can occur following very small amounts of rain, the resulting lesions occurring mainly in leaf axils (p. 259). Pyrenopeziza leaf spot of oil seed rape, like barley leaf blotch a splash-borne disease, also demonstrated its ability to develop in spite of the drought thus underlining its potential danger in more normal seasons (p. 270). The increase in this disease associated with treatments with the herbicide dalapon was confirmed (p. 270).

The work on these two splash-borne diseases reflects an increasing interest in this group of diseases which are of importance particularly in cereal production. Field work on these will be augmented in the coming year by work in the new rain tower and wind tunnel with the help of Physics Department. The work will concentrate initially on the movement in cereals under controlled conditions of spores of cereal pathogens, with emphasis on those that are splash-borne, in order to improve our knowledge of epidemiology and hence our ability to control them. The physical attributes of cereal and other plants and of crop canopies and the effect of these on movement and deposition of droplets and particles within crops will be studied and it is confidently expected that the information we expect to gain will find application in areas other than plant pathology.

The possibility of combining the beneficial effects of take-all decline and the ability of some members of the *Gaeumannomyces/Phialophora* complex to decrease take-all is reported (p. 262) and encourages us to expand our investigations on biological control in parallel with continuing studies of take-all and its epidemiology. We have evidence that direct drilling has little effect on take-all on two sites but that on one of them where it decreased eyespot by 50% in 1975, fewer plants again had eyespot in 1976 (p. 264).

Last year's prediction that there would be little infection of winter-sown cereals with barley yellow dwarf virus was borne out in practice but nevertheless insecticides increased yield (p. 256). In spring barley, later sowings had larger number of aphids and four times as much virus infection as earlier sowings and 36% less yield. Unusually variable results in fungicide experiments reported in 1975 are explained by interference by plots treated with triadimefon which is now known to be active in its vapour phase against mildew (p. 259). Yield of spring barley was increased most by fungicides when nitrogen was applied early (by 1 t ha^{-1} at 90 kg N ha^{-1}). Plots without fungicide had a lower maximum yield with more nitrogen (p. 258). Variety mixtures for mildew control were tested a second year and although some showed less mildew than the component varieties, yield benefits were not large (p. 258).

Among the grasses and forage crops most effort was applied to virus diseases of ryegrass (p. 265), but clovers received some attention also. Red clover necrotic mosaic virus has been identified in several crops of red clover and the possibility of its being seed-borne is under investigation (p. 266). A 'new' virus of oats which strongly resembles a soil-borne virus of wheat not recorded in Britain is under investigation (p. 256), and another unusual virus of sugar beet has been shown to be seed-borne and transmitted through both ovule and pollen (p. 251).

Because of the interest in grain legumes, their disease problems are being investigated in anticipation of an expanded acreage (p. 268). Insecticides reduced the spread of field bean viruses in unrogued crops in 1975 but failed to decrease infection in seed progeny. The benefits of roguing are under investigation (p. 269).

Gangrene remains the major obstacle to improving the health of the potato crop. We are seeking to improve our techniques in attempts to identify sources of infection and their relative importance in the re-infection of stem cutting material, whose anticipated benefits in seed health have yet to be achieved. Improvement of fungicide efficiency

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remains one of our aims, but the low level of gangrene in our experiments has hindered progress (p. 273).

Properties of viruses and virus diseases

Uncoating of tobacco mosaic virus on the cell surface. It is known that infiltrating TMV into the intercellular spaces of susceptible plants does not cause infection provided the cells are not wounded. When TMV at 100 μg ml^{-1} was so infiltrated into *Nicotiana tabacum* cv. Xanthi-nc (0·5 ml virus solution g^{-1} leaf) about half of the virus disappeared in 24 h suggesting that the virus was uncoated and the RNA inactivated. The loss of virus was demonstrated both by infectivity tests and by counting virus particles in the electron microscope.

When leaves of *Phaseolus vulgaris*, immune to infection with TMV, were inoculated by rubbing with 100 μg ml^{-1} TMV, 50–70% of the adsorbed inoculum lost its infectivity in 24 h. In this case we do not know how much virus entered the cells or was adsorbed on the leaf surface. Leaves dipped for 3 min in 100 μg ml^{-1} of TMV and washed, adsorbed a similar amount of virus on their surface as when rubbed and between 50 and 70% of the inoculum was lost within 24 h. The decrease in infectivity of the adsorbed inoculum was less in leaves kept in the dark than in the light. If an enzyme is responsible for uncoating the virus, it is possible that its activity is less in the dark when protein hydrolysis takes place. (Kassanis and Kenten)

Inhibition of TMV multiplication by rabbit serum. The multiplication of TMV in tobacco protoplasts was almost completely inhibited when normal rabbit serum was added to the incubation medium at dilution up to about 1/300, depending on the individual serum. The inhibition was not caused by the globulin or albumin fractions of the serum but by a component that is denatured when stored unfrozen or heated at 56°C for 30 min. Virus multiplication was inhibited when serum was added up to 7 h after inoculating the protoplasts but not after 10 h. There is a strong affinity between the serum component and the plasmalemma of the protoplast because virus inhibition occurred even when the protoplasts were washed with a mannitol solution after exposure to the serum for 1 min. The inhibiting effect was partly reversed by adding 30–40 mM-$CaCl_2$ to the incubation medium in which 10 mM-$MnCl_2$ is normally present. It seems that one of the effects of the serum component is to immobilise Ca^{2+} needed for proper physiological functioning of the protoplasts or the multiplication of TMV or both. (Kassanis, White and Woods)

Cryptic virus of sugar beet. Last year we described a spherical virus, 30 nm diameter which was present at low concentration in 90% of sugar-beet plants although they appeared normal. Purified preparations of the virus gave one sedimenting boundary of 118–124S in the analytical ultracentrifuge and three bands in CsCl gradients with buoyant densities of 1·36, 1·37 and 1·38 g ml^{-1}, suggesting the presence of more than one virus. To verify this we cloned individual plants by rooting 15–20 cuttings taken from a large root and purified virus from each of several such clones. These purified preparations gave one, two or three bands in CsCl gradients suggesting that at least three different seed-transmitted viruses or strains can be found in symptomless sugar-beet plants.

We have transmitted one or more of these viruses by grafting infected roots onto healthy roots but not by mechanical inoculation. To find out if the viruses are transmitted by pollen, Professor G. E. Russell, at the University of Newcastle upon Tyne, has inter-crossed some of the plants variously identified last year as virus-free or infected. All plants grown from seed obtained by inter-crossing infected plants were infected and all those obtained by inter-crossing healthy plants were healthy. Crosses between healthy and

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infected plants showed that the virus was transmitted through both ovule and pollen. (Kassanis, White and Woods)

Virus diseases of tropical crops

A virus disease of cocoa in N. Sumatra. A disease of cocoa in N. Sumatra, which causes leaf symptoms in the local cocoa ranging from a clearing of the major veins to a more complex mosaic pattern, has been transmitted by grafting and by the mealybug *Planococcus citri*. Bacilliform particles (139 nm long; 30 nm wide) similar in size and shape to those of cocoa swollen shoot virus were found in preparations from diseased leaves suggesting that the disease is induced by infection with a virus of the cocoa swollen shoot group. Infected West African Amelonado seedlings show only mild mosaic leaf symptoms but some local Trinitario seedlings from Ghana developed a severe mosaic suggesting that they were intolerant of the virus. (Kenten and Woods)

***Viruses infecting arracacha* (Arracacia xanthorhiza).** A mosaic disease of arracacha in Peru may be caused by virus infection. Two viruses, provisionally named arracacha viruses A and X have been isolated from extracts of diseased leaves. Both viruses are readily transmitted mechanically and infect many herbaceous species, virus A often inducing chlorotic or necrotic rings on inoculated leaves. Purified preparations of virus A contain numerous particles *c.* 26 nm in diameter with a hexagonal profile when mounted in neutral phosphotungstate. The virus sediments as three components with sedimentation coefficients of 50S, 92S and 125S and buoyant densities at pH 7 in CsCl of 1·306, 1·439 and 1·521 respectively. The absorption spectrum of the 50S component was typical of a protein while spectra of the other two components resembled those of nucleoproteins. All three components contained a single protein subunit of mol. wt. *c.* $5{\cdot}6 \times 10^4$ The properties of virus A suggest that it may be a member of the NEPO group but it did not precipitate with antisera to the known common NEPO viruses. (Kenten, with Dr. R. A. C. Jones, International Potato Centre, Peru)

Strains of pepper veinal mottle virus from solanaceous crops in W. Africa. Strains of pepper veinal mottle virus (PVMV), a potyvirus first found infecting peppers in the eastern region of Ghana (*Rothamsted Report for 1970*, Part 1, 124) have been found to cause diseases of tomatoes and peppers in Nigeria and garden egg plants (*Solanum melongena*) in Ghana. Four strains, one each from infected tomato, pepper (Nigeria), garden egg plant and *Solanum integrifolium* (Ghana) have been studied. All were transmitted in the non-persistent manner by *Myzus persicae*. The virus strains were very similar serologically, but were readily distinguished by their differential reactions to host plants. For example, the *S. melongena* strain failed to infect peppers or tomatoes. The *S. melongena* cultivar Moneymaker could not be infected with any of the virus strains even by grafting and may be immune, suggesting the possibility of genetic control of PVMV infection in *S. melongena*. (Kenten, with Dr. A. A. Brunt, Glasshouse Crops Research Institute)

***Viruses of taro* (Colocasia esculenta)**

Transmission and cause of alomae. Taro on Malaita affected with the lethal alomae disease contains two bacilliform virus particles of different sizes (Kenten & Woods, PANS (1973) **19,** No. 1, 38–41). The smaller particle may be latent in all field-grown alomae-susceptible cultivars and its multiplication 'triggered' when the large particle is introduced by the plant-hopper *Tarophagus proserpina*, inducing alomae symptoms associated with the two viruses (*Rothamsted Report for 1975*, Part 1, 245). Further

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transmission tests in the Solomon Islands and at Rothamsted have failed to induce alomae symptoms on field-grown susceptible cultivars using hoppers fed on plants containing only the large particle. Tests using virus-free seedlings and tissue-cultured plants have confirmed the previous conclusion that hoppers transmit only the large particle.

The cause of alomae is still not conclusively proven since two plants infected with both viruses did not develop alomae symptoms at Rothamsted. This may, however, merely reflect an environmental effect on host/virus interaction.

Transmission characteristics of the large particle. Hoppers acquired the virus in a minimum of three days and became effective transmitters within 15 days. The virus was not transovarially transmitted. Only 5% of hoppers caught in the field but over 50% of those fed continuously on a virus source plant for 21 days transmitted the virus. Both males and females were equally efficient vectors.

New records. Small bacilliform particles were found in taro exhibiting alomae symptoms from Choiseul, in stunted taro with necrotic leaves from Fiji and in *Xanthosoma* (an aroid related to taro) with chlorotic, puckered leaves from Raratonga. (Dabek)

Macana disease of* Furcraea spp. *in Colombia. Spherical virus particles measuring *c.* 30 nm have been seen in macana-affected but not in healthy *Furcraea macrophylla* (Agavaceae) plants from Colombia, South America (*Rothamsted Report for 1975*, Part 1, 245–6). The virus has been transmitted mechanically to 15 of 26 *F. macrophylla* test plants and produced typical macana symptoms, confirming it as the causal agent of the disease. The successful inoculum consisted of particle preparations made by butanol-treatment and differential centrifugation of infected *Furcraea* sap. Crude sap, neat or diluted to 10^{-4}, did not infect 20 *F. macrophylla* test plants possibly because of the presence of inhibitors. A range of herbaceous plants from families other than Agavaceae developed no symptoms after inoculation with the purified virus and no particles were detected in their tissues by electron miscroscopy.

Purified virus preparations show a single component in the analytical ultracentrifuge with a sedimentation coefficient of 126S. The buoyant density in CsCl, 1·384, suggests the particles contain about 20% RNA. Acrylamide-gel electrophoresis indicated that the virus was composed of single-stranded RNA, mol. wt. $1{\cdot}33 \times 10^6$ and a single type of protein, mol. wt. 4×10^4. These combined properties are different from those of any well-characterised plant virus but some features are common to carnation ringspot, tomato bushy stunt and turnip crinkle viruses. Serologically the virus was unrelated to these three viruses and brome mosaic virus. (Dabek and Carpenter)

Mycoplasma and virus infections of* Ipomaea batatas *in the Solomon Islands. Two diseases of *Ipomaea batatas* (sweet potato) characterised by witches broom and little leaf symptoms (WBLL) are known in the Solomon Islands. One affects the cultivated sweet potato, cv. Gina, on Guadalcanal and the other a weed form on Malaita. Both are associated with mycoplasma-like organisms (MLO) which seem to be causal since symptom remission occurs after treatment with tetracycline but not penicillin. The two MLO may be different strains or species, however, since the diseased weed can induce WBLL symptoms when grafted to healthy cv. Gina but no symptoms have occurred on the healthy weed after grafting with naturally infected cv. Gina. Both the diseased cv. Gina and weed however, also contain virus particles which seem to cause no obvious symptoms.

Diseased cv. Gina often contains a long rod-shaped virus 783 $\pm$ 25 nm. It is trans-

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missible mechanically to *Chenopodium amaranticolor* and *C. quinoa* (local lesion response), by grafting to at least three sweet potato cultivars and *Ipomaea setosa*, but not by *Myzus persicae* or *Aphis gossypii*. The partially purified virus did not react with antisera of sweet potato mild mottle (Hollings *et al.*, *Annals of Applied Biology* (1976) **82**, 511–528,) and seems to differ from other sweet potato viruses recorded so far. A spherical virus *c.* 50 nm in diameter and undetectable by electron microscopy of negatively stained leaf sap was also present in the partially purified rod preparations.

The diseased weed also contains a spherical virus particle *c.* 60 nm in diameter transmissible by grafting to *I. setosa* in which it is detectable by electron microscopy. This phloem-restricted virus was not sap transmissible to a range of herbaceous indicator plants even after partial purification. (Dabek)

Biodeterioration

The quality of stored agricultural produce may be greatly decreased by moulding. Appearance and food value may be affected, germinability may be lost and in addition the spores of micro-organisms causing the spoilage may produce disease in man and animals through allergy or infection and some fungi may produce toxic metabolites. Our work concerns the identification of the moulds, the sources from which they come, conditions of storage that favour their growth and chemicals to prevent moulding.

Microflora and grain quality. Cereal plants may be colonised by a wide range of micro-organisms before harvest in addition to recognised pathogenic fungi. Some of these may discolour the ear and affect flour quality. Others may provide inoculum of species causing deterioration in store.

During ripening. Although not detected in the ears of spring or winter-sown wheat before emergence from the leaf sheaths, micro-organisms, mainly bacteria, yeasts, *Hyalodendron*, *Verticillium*, *Alternaria*, *Aureobasidium*, *Cladosporium*, *Mycelia sterilia*, *Fusarium*, *Arthrinium*, *Acremoniella* and *Botrytis* were found a few days afterwards. As ripening progressed their numbers increased greatly and small numbers of 'storage fungi' were found close to harvest. The grain microflora was modified by applying protectant and systemic fungicides at growth stages 10·0, 11·0 and 11·4 or at two or more of these stages, with or without tridemorph and benodanil sprays against mildew and rust. Captafol was most effective in controlling the grain surface microflora and triadimefon was least effective with benomyl intermediate. Also, captafol was the only fungicide significantly to reduce numbers of bacteria. However, yields were depressed by drought and no increases in yield or germinability in response to fungicide treatment could be detected. Tridemorph sprays decreased mildew better on spring wheat but triadimefon applied at growth stage 10 gave good control of the disease on the flag leaf. Benomyl supplemented the effect of tridemorph in controlling mildew on winter wheat when it was applied at growth stage 10. Other pathogens were few. Altering the microclimate of the ear by irrigation and lodging increased the incidence of *Fusarium* and *Penicillium* species on spring wheat grain but rate of application of nitrogenous fertiliser to the crop had little effect. Fungi common on grain stored too damp were more frequent on grain from lodged, irrigated crops than from crops supported to prevent lodging.

Microflora of stored barley. Fungi that colonised the grain before harvest, e.g. *Alternaria*, *Cladosporium*, *Epicoccum*, *Fusarium* and *Hyalodendron*, continued to supply half the viable propagules in grain stored four months with 17·5% water content or less. However, no 'field fungi' survived in stored grain containing 17·8% water or more after

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four months. Only grain harvested with a water content of 20·9% heated spontaneously during storage, to a maximum temperature of 36°C. Spoilage was rapid and thermophilous fungi including *Aspergillus flavus. A. candidus, Penicillium capsulatum* and *P. piceum* became numerous. The species of *Aspergillus* and *Penicillium* isolated and their abundance was correlated with grain water content. Grain containing 16·6% water or less showed no detectable deterioration after four months storage.

Effect of pre-harvest fungicidal treatment on storage microflora. Small quantities of grain (1 kg) were stored in Polythene bags at a range of temperatures (5, 10, 15 and 20°C) with an initial water content of 19%. The microflora was assessed after five months and the counts of viable propagules following storage at 5°C are shown in Table 1 Yeasts were significantly fewer in grain treated before harvest with benodanil and benomyl, *Aspergillus versicolor* was decreased by all four fungicides and numbers of *Cladosporium* were reduced following captafol and benomyl treatments. Captafol, benodanil and benomyl also decreased numbers of *Penicillium verrucosum.* (Hill)

Microflora of cereal grain from Iran. Grain samples from regions of Iran where oesophageal cancer is common, contained few micro-organisms unless they had been stored in

TABLE 1

Residual effects of fungicides applied to barley during ripening on microflora during storage at 5° C

Colony type	Treatment 0	TR	CA	BA	BE	Standard error of difference
		(propagules g^{-1} grain × 10^{-4})				
Total fungi	110	281	78	51	80	99·9
Yeasts	0·8	0·5	0·5	0·1	0·1	0·29
Aspergillus versicolor	1·3	0·4	0·3	0·3	0·3	0·47
Cladosporium spp.	0·2	0·1	0·0	0·1	0·0	0·09
Penicillium verrucosum	104	274	66	43	77	99·2

Key: Treatment, crop sprayed three times between heading and harvest with: TR, tridemorph; or CA, captafol; or BA, benodanil; or BE, benomyl. 0, unsprayed control.

underground pits. *Aspergillus restrictus* was then common. No toxic fungal metabolites could be detected in any sample. (Lacey, with Lord, Chemical Liaison Unit and Mr. A. Hacking, ADAS, Shardlow)

The air spora of cotton mills. As part of an Employment Medical Advisory Service study, periodic air samples have been taken in a new cotton mill in N.E. England over a period of two years to identify and enumerate airborne fungi, actinomycetes, bacteria and other dust. Up to $4{\cdot}4 \times 10^5$ fungus spores, $1{\cdot}2 \times 10^6$ 'actinomycete spores + bacteria', $8{\cdot}3 \times 10^5$ cotton fibres and $1{\cdot}1 \times 10^7$ dust particles m^{-3} air were found. Most air-borne particles of all types usually occurred at locations where bales of cotton were opened with fewer at sites of subsequent processing; but cotton fibres were often numerous around speed and ring frames. Gram-negative bacteria predominated with largest numbers at bale-opening, scutching and weaving sites. The most numerous fungi were *Cladosporium* spp., *Penicillium* spp., *Aspergillus versicolor* and *A. niger.* Actinomycetes included *Actinomadura dassonvillei, Streptomyces* spp., *Thermoactinomyces vulgaris* and *Micropolyspora faeni*, but their numbers were usually small. However, on one occasion *M. faeni* and *T. vulgaris* were common in the air at bale-opening, scutching and carding sites. Even greater numbers of *M. faeni* were found in a single set of samples taken in a

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Lancashire mill. Here there were up to $1{\cdot}2 \times 10^6$ fungus spores, $2{\cdot}3 \times 10^6$ 'actinomycete spores + bacteria', $5{\cdot}7 \times 10^5$ cotton fibres and $4{\cdot}7 \times 10^6$ dust particles m^{-3} air. *M. faeni* was by far the most numerous organism and was common in the factory through to the speed-frame stage of processing. (Lacey)

Cereal diseases

Barley yellow dwarf virus (BYDV)

Infective aphids. Fewer cereal aphids were infective than last year and although the first infective aphid was, as usual, *Rhopalosiphum padi*, it was caught on 28 May, 13 days later than last year. About 3% of alate *Macrosiphum* (*Sitobion*) *avenae*, 4% of *R. padi* and 1% of *Metopolophium dirhodum*, but no *M. festucae* or *R. insertum*, transmitted BYDV to test plants. Because of its greater number *M.* (*S.*) *avenae* was the most frequent vector.

Winter cereals. As predicted last year (*Rothamsted Report for 1975*, Part 1, 250) there was little infection of winter-sown cereals and no difference in virus infection between crops sown on different dates. Therefore increases of 6% in yield of October and November-sown oats, cv. Peniarth, and of 7–8% in September, October and November-sown wheat, cv. Cappelle-Desprez, when treated with phorate at drilling, were unexpected. Because of the dry winter the phorate appears to have had an effect on aphid immigrants the following spring. There were twice as many aphids on untreated as on treated wheat in early June, and 40% more when aphids were most numerous. In contrast a spray of menazon on 7 May did little to affect a later increase in aphid number and only increased yield by 2%.

Although fewer were infective many more aphids fed on winter wheat, some untreated crops having more than 100 *M.* (*S.*) *avenae* per ear, so little of the increase in yield can be attributed to prevention of infection by BYDV. (Plumb)

A 'new' virus of oats. In April, the characteristic lenticular chlorotic lesions of oat mosaic were found on almost every plant of winter oats cv. Peniarth in two fields totalling 10 ha near Cranbrook, Kent. Electron microscopy of sap showed, however, not only oat mosaic virus (OMV) but more numerous particles of another virus. In contrast to OMV which has slightly flexuous particles 700 × 12 nm the second virus had tubular particles of two lengths, 150 and 300 × 20 nm, with four times as many short as long particles. When the crop was in ear, patches of plants, often in poorly drained areas, showed striking bright yellow stripes on the flag and second leaves, while symptoms of oat mosaic were difficult to find. These stripy plants contained large amounts of the tubular virus. The virus was manually inoculated to oats cv. Blenda but further transfers were decreasingly successful until no further infection occurred. None of the manually inoculated plants contained OMV and the concentration of the tubular virus was less than in natural infections.

The striped leaves and the associated tubular virus seem identical with those formerly reported from Devon, also in association with OMV (Macfarlane, Jenkins & Melville, *Plant Pathology* (1968) **17,** 167–170) and then likened to tobacco rattle virus. Oats, cv. Powys, grown under cool conditions this year in soil collected from that site in 1967 and stored dry at 5°C, developed mosaic and stripes and contained both OMV and the tubular virus. Manual inoculation of sap from these plants caused local lesions on *Chenopodium amaranticolor*, *Nicotiana tabacum* and *N. clevelandii*. Tubular particles were found in the lesions but virus multiplication seems limited and much affected by environment. OMV was also found in winter oats, cv. Maris Osprey, showing mosaic symptoms,

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from Newport, Salop. Zoosporangia of *Polymyxa graminis*, the probable vector of OMV, were found in the roots which were then placed in water together with oat seedlings as bait. Of six seedlings, three eventually showed mosaic symptoms and contained OMV particles. Surprisingly, the tubular virus was also found in some leaf samples from the bait plants. Previously, when we first obtained oat mosaic virus from another Devon soil, a similar tubular virus was occasionally found.

Morphologically the virus strongly resembles soil-borne wheat mosaic virus (SBWMV) which is transmitted by *Polymyxa graminis* but is not recorded from Britain and has not been found to infect oats. Survival of the oat tubular virus in dried soil, its occurrence in wet areas, association with OMV and similarity to SBWMV suggest that it may be transmitted by a zoosporic fungus, possibly *Polymyxa graminis.* (Plumb and Macfarlane)

Effects of sowing dates on pathogens. A replicated, factorial experiment in which spring barley, cv. Julia, was sown on 4 March and 13 April, tested the effects of insecticide (phorate to the seed-bed and a menazon spray on 4 June) and fungicide (ethirimol seed dressing plus tridemorph sprays on 27 May and 7 July, the latter only to late-sown plots). Mildew quickly became more severe on the later than the early sowings. Late-sown plots also had nearly four times as many plants infected by barley yellow dwarf virus on 14 June (although maximum infection was only 10%) and twice as many aphids throughout the season, as those sown early.

On average the late-sown plots yielded 36% less than the early-sown (3·30 and 5·15 t ha^{-1} respectively). Both phorate and menazon decreased aphid number and virus incidence. Phorate increased yield more than menazon on the early-sown barley but the reverse was true on the later sown plots, possibly because the dry conditions following late-sowing restricted uptake. Mildew was much decreased by the fungicides which increased yield of early and late-sown barley by similar amounts. However, proportional responses to all chemicals were larger on the late-sown barley. (Plumb and Jenkyn)

Interference between plots in field experiments. Further information on the extent to which interference between plots may affect results from experiments with pathogens, such as *Erysiphe graminis*, which have easily dispersed spores, has been obtained from a field experiment using a 'serially balanced' design (*Rothamsted Report for 1975*, Part 1, 133). Such designs allow the modifying effects of left-hand and right-hand neighbours of each treatment to be separately estimated. In our experiment, plots were either untreated, sprayed once on 18 May or 27 May or sprayed three times on 18 May, 27 May and 7 June. The results have not yet been fully analysed but yields showed strong evidence of regular variation across the site and appropriate adjustments were made by covariance. Yields were significantly affected by neighbours to the east and, to a smaller extent, by neighbours to the west. The plots sprayed on 18 May were most affected and yielded 4·48, 4·77 and 5·10 t ha^{-1}, where neighbours to the east were respectively untreated, sprayed on 27 May and repeatedly sprayed. (Jenkyn and Bainbridge, with Dyke, Field Experiments Section)

Powdery mildew on barley

Winter barley. A factorial experiment tested the effects of tridemorph (to control *E. graminis*) applied at different times to winter barley (cv. Astrix) sown on 24 September or 6 November at 78 or 156 kg ha^{-1}. The tridemorph sprays were applied during winter (14 November and 25 February to the early- and late-sown barley respectively), early spring (9 April) or late spring (14 May). Nitrogen at 75 kg ha^{-1} was applied on 9 March or 27 April.

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Mildew was prevalent during late autumn and winter on the early-sown barley (*c.* 1 and 17% of the leaf area infected on unsprayed plants on 11 November and 12 January respectively) and was much decreased by tridemorph. The late-sown barley did not emerge until January and little mildew was recorded until early spring. On 5 April, both early- and late-sown barley had *c.* 5% of the leaf area affected by mildew. Later, however, the early-sown plots had much less disease than the late-sown (12 and 24% respectively of the area of the top three leaves on 16 June).

The average yield of early- and late-sown plots was 7·90 and 4·42 t ha^{-1} respectively. Seed-rate had little effect on yield but nitrogen applied in April gave better yields than that applied in March. Tridemorph applied in winter (14 November or 25 February) or early spring (9 April) increased yield of both early- and late-sown crops but the late spray (14 May) had no significant effect on the yield of either. (Bainbridge, Finney and Jenkyn)

Spring barley. The mild spring provided almost ideal conditions for the growth of *E. graminis* and, in many unprotected crops, the disease was severe by the end of May. Subsequently, however, the hot, dry weather hindered the development of the disease so that it was only on very susceptible varieties that it remained severe throughout the season.

Effects on yield. As in 1975, spring barley (cv. Zephyr, sown 22 March) showed a greater response to increasing amounts of applied nitrogen where tridemorph was applied to control midlew than in untreated plots. Yields were greater where nitrogen was applied soon after sowing (1 April) or as a split dressing (half on 1 April and half on 21 May) than where it was all applied as a top dressing on 21 May but response to increasing amounts of nitrogen applied late was surprisingly good in such a dry year. Averaged over these different times of applying nitrogen, the best yield from fungicide-treated plots (5·05 t ha^{-1}) was obtained with 90 kg N ha^{-1} and it was with this amount of nitrogen that tridemorph increased yield most (by over 1 t ha^{-1}). The average effect of tridemorph in this experiment was to increase yield by 0·68 t ha^{-1}. Untreated plots needed 110 kg N ha^{-1} to give their best yield (4·24 t ha^{-1}). (Jenkyn and Finney)

Variety mixtures. In 1976 we continued, for the second year, co-operative work with Dr. Martin Wolfe of the Plant Breeding Institute, Cambridge, on the development of mildew in barley crops sown with mixtures of varieties containing different resistance genes. Further details can be obtained from the *Reports of the Plant Breeding Institute for 1975 and 1976*.

In an experiment at Balsham, near Cambridge, fewer spores were deposited on sticky cylinder traps above plots of cv. Tern than above plots of Midas or Hassan (total numbers of spores, accumulated from 24 May to 5 July were *c.* 6900, 8300 and 10 800 cm^{-2}, respectively). Catches above plots sown with 1:1 mixtures of Hassan and Midas, Tern and Midas, or Hassan and Tern did not differ from the mean of the catches above the component varieties grown separately. However, catches above a Hassan-Midas-Tern mixture were smaller by about 10% than the mean for the components.

At Rothamsted, pure stands of Hassan, Midas, Wing and Lofa Abed were compared with a mixture containing equal proportions of these four varieties. Estimates of disease on 19 May and subsequently showed that mildew in the mixture was consistently less severe than the mean of the component varieties (mildew in the mixture ranged from *c.* 40–60% of the components mean). The mixture yielded 4·01 t grain ha^{-1}, very little more than the highest yielding variety, Wing (3·95 t ha^{-1}) but *c.* 5% more than the mean yield of the component varieties. (Jenkyn and Mawby)

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Observations on *Rhynchosporium secalis*

Viability of spores. When spores washed from plants either sprayed with paraquat or unsprayed (*Rothamsted Report for 1975*, Part 1, 258) were counted a small number were found to have germinated before removal from the plants. These were recorded over a period of five weeks and included spores washed from both sprayed and unsprayed plants. No significant differences were found between any of the treatments.

In early January suspensions of spores from unsprayed plots and plots sprayed with paraquat eight weeks and five weeks previously, adjusted to equal concentrations, were serially diluted and used to inoculate plants of cv. Maris Otter. The mean probable number of viable spores was calculated to be very small. There was no difference in viability between unsprayed volunteers and those sprayed five weeks previously but significantly fewer spores were viable on volunteers sprayed eight weeks previously.

Weekly assessment of viability of spores washed from stubble and volunteers showed that between mid-August and mid-October the viability of spores from stubble was in the range 0·2–2·7% and of spores from volunteers in October, 0·1–2·2%.

Spread. A comparison was made between the number of lesions developing on plants (cv. Maris Otter) in pots placed in a crop of the same variety or at the centre of circles (diameters 0·5, 1·0, 1·5, 2·0 and 2·5 m) from which the crop had been cleared. Plants were removed when rain ceased so that conditions of drying were comparable. Although there were 22 rain days between early May and late July spread was detected on only four occasions. The steepest dispersal gradient was found following the greatest rainfall (35 mm) when plants exposed in the crop developed 175 lesions and those in 0·5, 1·0, 1·5, 2·0 and 2·5 m circles developed 147, 35, 11, 7 and 2 lesions respectively.

The time interval between infection dates enabled new lesions on the crop to be correlated accurately with the occasion when spread occurred. New lesions found on 9 June resulted from spread on 20 May when there were two showers (0·5 mm) in the early evening. On 250 stems examined, *c.* 40% of the top three leaves were infected in the leaf axils while less than 4% had leaf-blade lesions. These figures suggest that many infections can follow very small amounts of rain especially on plant parts on which moisture tends to persist.

Spore numbers on infected leaves. Jenkyn and Griffiths (*Transactions of the British Mycological Society* (1976) **66,** (2)) suggested that changes in the amounts of carbohydrate and nitrogen in ageing leaves may influence sporulation of *R. secalis*. The transitory increase in spore number on infected leaves sprayed with paraquat (*Rothamsted Report for 1975*, Part 1, 258) may be a result of these changes. In most summers new lesions develop frequently on field crops so that sporulation of single lesions cannot easily be monitored. The summer of 1976 provided exceptional conditions. Following infection occasions on 13–14 April and 20 May newly infected leaves each with a single lesion were marked with coloured wires and a sample of each was removed each week for spore counts. Lesions following the second date were all in leaf axils. Following the first infection date peak sporulation occurred when the leaves were almost dead; no marked peak was recorded on leaves infected at the later date. (Stedman)

Fungicides on spring and winter wheat. Last year we reported a randomised experiment on spring wheat (cv. Kleiber) which tested a number of foliar fungicides (*Rothamsted Report for 1975*, Part 1, 252) including triadimefon. This fungicide significantly increased yields although the results from the experiment were unusually variable. Subsequent examination of the mildew data showed that much of the variability in disease could be related

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to the proximity of plots to other plots sprayed with triadimefon. Untreated plots, for example, had 13, 9 and 1% mildew, on the top two leaves on 1 August 1975, where neither, one or both of the neighbouring plots, respectively, received sprays of triadimefon. Such large effects of triadimefon on neighbouring plots appear to be due to considerable vapour phase activity, recently demonstrated by the manufacturers (Bayer). (Jenkyn and Bainbridge)

Winter wheat (cv. Cama) sown on 6 November was treated with 'U-34910' (Upjohn Ltd.) applied as a seed dressing, or with sprays of 'ME-125' (Merck, Sharp and Dohme), triadimefon or wettable sulphur. Sulphur was included because, although it is used on cereals in Europe, it is seldom used in the U.K. Mildew, the only prevalent foliar disease, was much decreased throughout the season by an early spray of triadimefon, (14 May). A later spray (15 June) had very little effect on the disease. 'ME-125' had only a slight effect on mildew and wettable sulphur almost none, in spite of high temperatures. Plots again tended to have less disease if their neighbours had been sprayed with triadimefon, but effects were smaller than in 1975, probably because plots were separated from one another by guard areas.

Eyespot was moderately severe. It was only slightly decreased by triadimefon but sprays were perhaps applied later than the best date. Take-all and brown foot rot were both slight and not affected by treatments. Yield was increased by the early sprays of 'ME-125', even though they had little effect on disease, and by the early, and early plus late sprays of triadimefon. (Jenkyn and Prew)

Eyespot on winter wheat varieties. Out of the eight wheat varieties grown in the Rothamsted variety trial after wheat the semi-dwarf Maris Fundin was again the most attacked by eyespot, but the other semi-dwarf, Hobbit, was no more infected than Cappelle-Desprez. Carbendazim applied on 21 May (later than intended because of persistent winds) decreased eyespot on all varieties, but increased yield of none. Take-all was scarce, but all varieties were badly infested by blackgrass (*Alopecurus myosuroides*) and yields averaged only 3·92 t ha^{-1}. (Slope and Gutteridge, with Moffitt, Farm)

Take-all disease. In these reports the following abbreviations are used for simplicity:

Gaeumannomyces graminis var *tritici* = Ggt;
G. graminis var *graminis* = Ggg;
Phialophora radicicola var *radicicola* = Prr;
P. radicicola var *graminicola* = Prg.

Effect of phosphate fertiliser on take-all of wheat. From 1960 the three series of the Residual Phosphate experiment were cropped in rotation with swedes, potatoes, barley, but successive wheat crops are now grown after the last barley on each series. In April take-all was scarce in the first wheat after barley (Series I), but common in the second (Series II) and third (Series III) wheats. Much of this infection was unusually severe for the time of year but subsequently few new roots became infected (presumably because of the hot, dry summer), so by July infection was still mostly restricted to seminal roots. Nevertheless, the crops on Series II and III showed symptoms of take-all damage after ear emergence and yields were decreased, especially where P was deficient. Large amounts of P fertiliser decreased take-all in the second wheat after barley but had only small effects in the third wheat. Grain yields decreased with successive wheat cropping at all amounts of P but the fall was largest where P was deficient. However, the coincidence of take-all and yield was not consistent enough to suggest that take-all was the only factor, associated with successive wheat cropping, influencing response to P fertiliser.

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Even so, it is clear that farmers would be ill advised to risk shortage of P where growing wheat after wheat. (Slope and Gutteridge, with G. E. G. Mattingly, Chemistry Department)

Epidemiology of take-all. Assessments of take-all in field crops made by recording lesions visible to the naked eye provide an acceptable measure of damage done to the crop assessed, but we have long doubted their value for measuring potential inoculum left in the soil on crop residues. These doubts were confirmed by our work on take-all after leys: first wheat crops after lucerne and grass leys had similar amounts of take-all in July (<5% plants with lesioned roots) but soils taken from stubbles in September were much more infective to wheat seedlings (in assay experiments) after lucerne than after grass and second wheats after lucerne were more attacked by take-all in the field (*Rothamsted Report for 1975*, Part 1, 255). These differences were associated with, probably caused by, differing populations of the root infecting fungus Prg. To be able to define when and how Prg affects populations of the take-all fungus Ggt we need a better understanding of the development of the take-all fungus than we achieve by assessing take-all lesions. To this end a preliminary study was begun in 1975 on a first wheat crop after winter oats. Soil cores taken at intervals during crop growth and from stubbles after harvest were assayed for infectivity by sowing with wheat grown on for five weeks in a growth room at 15/10°C day/night temperature. Also, on each occasion the roots of two plants taken close to the position of each of the 50 cores were examined for take-all lesions and a 1·5 cm piece cut (2 cm below the seed) from the oldest seminal root on each plant was surface sterilised and plated on potato dextrose agar (PDA). As expected, few plants had take-all lesions and Ggt was isolated from very few root pieces (never more than 3%); but the soil assays showed that infectivity increased to a peak during late June–July, then fell, so by late September infectivity was no more than in May (Table 2A). This rate

TABLE 2

Wheat seedling assay of take-all infectivity of soils, and the incidence of take-all in winter wheat after oats.

	Crop					Stubble		
	May	June	June	July	Aug.	Aug.	Sept.	Sept.
A. First wheat after oats (1975)	6	9	23	14	5	18	1	29
% soil cores with infected seedlings	30	60	74	74	64	46	52	18
No. of infected roots (50 cores)	18	123	176	261	173	89	120	57
% field plants with take-all	1	6	3	8	—	—	—	—
	Mar.	May	June	June	July	Aug.	Sept.	Sept.
B. First wheat after oats (1976)	22	10	7	28	20	9	6	27
% soil cores with infected seedlings	10	70	64	68	20	24	14	20
No. of infected roots (50 cores)	11	116	155	121	37	107	24	58
% field plants with take-all	3	0	5	3	4	—	—	—
C. Winter oats after barley (1976)								
% soil cores with infected seedlings	92	—	88	—	72	68	74	—
No. of infected roots (50 cores)	317	—	270	—	246	211	164	—

(oat plants not diagnosed for take-all lesions)
— no observation

of fall was greater than expected so the study was repeated on a first wheat on another site in 1976 (Table 2B) and soil from a winter oat crop after barley was also sampled (Table 2C). The pattern of infectivity in the wheat soil was similar to that in 1975 but, in

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sharp contrast, the initial large infectivity in the oat soil fell only slowly so that by early September infectivity was larger after oats than after wheat.

In 1976 take-all was slight in the second winter wheat on the 1975 site and previous assays of soils in September indicate that a following wheat crop will be severely attacked where 60–80% of soil cores infect seedlings but only lightly attacked where 10–20% infect seedlings. If these results apply generally, it seems that wheat crops in 1977 may be more at risk from take-all after a one-year break than after a previous wheat but our experience with the assay technique is not enough for us to make this disturbing prediction with confidence. (Slope, Gutteridge and Henden)

Biological control of take-all. Most reported experiments in which Prg has decreased root infection by the take-all fungus Ggt, have been done on seedlings using introduced inoculum of Ggt. To test whether Prg is effective on more mature plants and against natural populations of Ggt, soils were collected in February 1975 from four contrasting crop sequences of the 'Wheat after Intensive Barley' experiment on Little Knott field:

	Cropping				
Soil	1971	1972	1973	1974	1975
A	W7*	Fallow	Beans	W1	W2
B	W6	W7	Fallow	Beans	Beans
C	W5	W6	W7	Fallow	Beans
D	W11	W12	W13	W14	W15

* W=winter wheat; number after symbol is the number of consecutive wheat or barley crops.

Soils were sieved and half of each mixed with an inoculum of Prg prepared by macerating 100 test tube PDA cultures prepared during 1974 from various field samples in 6·6 kg sterilised sand (eight parts soil: one part inoculum by weight). Soils were potted in 12 cm diameter pots, sown with spring wheat cv. Kolibri on 25 March and kept in an unheated glasshouse. Plants from half the pots were examined in June (growth stage 10·5, flowering). The remainder were grown to maturity; after harvest the stubbles were inverted in each pot and resown on 27 October with winter wheat cv. Cappelle-Desprez. These plants were examined on 20 May 1976 at growth stage 10 (in 'boot'). Roots infected by Prg were scarce in soils without inoculum, but common in all with inoculum in both years. Adding Prg decreased take-all on seminal and crown roots in soils A and D taken from wheat crops. Take-all did not develop in soils B and C taken from bean crops, so we gained no information on the ability of Prg to suppress the build-up of Ggt. Take-all was more abundant in soil A than in the 'take-all decline' soil D but Prg decreased take-all in both (Table 3). This raises the possibility of gaining the benefits of both forms of biological control of take-all, if large enough populations of Prg can be established in continuous wheat soil. (Gutteridge and Slope)

TABLE 3

Effect of Prg inoculum on the percentage of wheat roots with take-all

	1975 Spring wheat				1976 Winter wheat			
	Without Prg		With Prg		Without Prg		With Prg	
Soil	Seminal	Crown	Seminal	Crown	Seminal	Crown	Seminal	Crown
A	42	16	18	2	61	45	10	2
B	1	0	1	0	0	0	0·4	0
C	1	0	0	0	0	0	0	0
D	37	10	27	6	15	14	2	1

Several fungi in the *Gaeumannomyces/Phialophora* group were grown on sterilised perlite with nutrients and sown with spring wheat in a field experiment designed to screen

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their ability to control natural take-all. Unfortunately the hot, dry summer suppressed disease development and even inoculum of a strongly pathogenic, virus-infected isolate of Ggt caused only moderate lesions on seminal roots of 36% of plants. The interest in the experiment therefore turned to how well the other ten isolates, which comprised weakly pathogenic Ggt, Prr, Prg and Ggg were able to colonise roots. Only one, an isolate of Ggg (G5 without virus) seemed promising in this respect, over half the plants exposed to it having one or more seminal roots colonised by readily visible runner hyphae and swollen lobate cells in July. This may have reflected the unusual weather in 1976. 1977 will afford an opportunity to test their colonising ability in another season and to assess the persistence of 1976 inoculum. G5 was avirulent when compared with Ggt (isolate Og12) in wheat infection tests in pots. Plants infected by Og12 had 23% more root axes but 80% of roots were lesioned and the plants stunted with blackened leaf sheaths and yellow-brown older leaves. G5 plants, however, were green and twice as heavy (fresh weight) despite having 38% of their roots colonised. (Rawlinson, Hornby and Muthyalu)

The use of take-all decline soil to decrease disease. In autumn 1974 a small experiment was set up to test in the field the finding (Pope and Hornby, *Annals of Applied Biology* (1975) **81,** 145–160) that small amounts of soil with take-all decline (D soil) added to soil in which take-all had not declined (U soil) decreased disease. D soil from two Rothamsted fields (Broadbalk, section 9, plot 3 andwas added at 2·27 kg m^{-2} (approx. Meadow) 1% by weight of the top 15 cm) to the seed-bed for a second winter wheat crop on Barnfield, where unimpeded take-all was expected. At this time the Barnfield soil caused fewer infections (2·5% roots infected) in bioassays than either Broadbalk soil (17%) or Meadow soil (46%). Perhaps because of hot summers take-all never exceeded 5% of roots infected in unamended Barnfield soil in 1975 or in 1976. There was no evidence of disease decrease in the amended plots and the treatments did not affect yields. Take-all in plots amended with Meadow soil differed little from unamended plots but the plots with Broadbalk soil had significantly more infected roots (16·5%) in July 1975, but not in 1976. It seems therefore that in some combinations of U and D soils, the D soil may have an effect contrary to that intended. (Hornby and Henden)

Diseases in reduced cultivation systems. In joint NIAE/Rothamsted experiments, previous work (*Rothamsted Report for* 1975, Part 1, 256–257) has shown that take-all at Rothamsted and Boxworth EHF, and eyespot at Rothamsted did not differ greatly with cultivations but that at Boxworth in 1975 the amount of eyespot on the direct drilled crop was only about half that of the other crops. More detailed work on both take-all and eyespot was done on these experiments in 1976.

Take-all profiles. In May, June and July soil blocks (30 cm deep × 20 cm wide along the row × 10 cm thick) were taken beneath a row of winter wheat by pin board from ploughed (PL), chisel ploughed (CP) and direct drilled (DD) plots. The soil blocks were soaked in water and deep frozen before washing, to improve root recovery. Examination of the root systems showed that at Rothamsted neither the amount of roots nor the incidence of take-all differed greatly between treatments. At Boxworth a larger percentage of roots was infected in the zones below 7 cm on PL than on CP or DD crops, particularly at the earliest sampling date, though the total number of roots infected at these depths was small. The 0–7 cm zone contains a high proportion of the total root system and many young roots. Although the greatest number of infected roots were found in this zone in all plots, except PL at the first sampling date at Boxworth, the percentage infection in this zone was therefore small. (Prew and Bater)

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Eyespot. In March (Boxworth) or April (Rothamsted) the number of straw bases on the soil surface and the percentage of these that produced spores of *Pseudocercosporella herpotrichoides* when incubated in a damp chamber at 10°C were recorded. The incidence of eyespot on the wheat plants in April was recorded for both sites. There were many more straw bases on the direct drilled plots but a smaller percentage produced spores and fewer plants had eyespot. (Prew)

Effects of root-infecting fungi on transport of materials in young wheat plants. The different effects of some root-infecting fungi on wheat were described in the *Rothamsted Report for 1975*, Part 1, 248–249. Further experiments have provided information about root anatomy, shoot water content, ion uptake and distribution of assimilates as infections developed in wheat plants grown in sand for five weeks. *Aureobasidium bolleyi* penetrated seminal roots most rapidly and within one week colonised and disrupted the stele near the apex and killed the meristem. Photosynthetic assimilates could not enter these roots and so active ion uptake and root growth ceased. In the shoots the subsequent decrease in K content may have decreased water content by affecting the osmotic potential of leaf cells. The death of seminal roots stimulated production of new crown roots during the second and subsequent weeks, possibly because assimilates were accumulating at the crown. *A. bolleyi* invaded only the epidermis of these crown roots, which functioned normally and aided rapid recovery of the plant.

Gaeumannomyces graminis also penetrated the stele of seminal roots within one week but shoot growth and ion uptake were unaffected. After another three days, however, all the phloem bundles had been destroyed (xylem strands remained intact until the fourth week) and photosynthetic assimilates no longer entered the infected roots. Consequently root elongation and the uptake of P and K ceased but the passive uptake of Mg and Ca continued. Shoot dry weight and water content were decreased and autoradiographs showed that assimilates were redistributed to newly formed crown roots. Initially these too were rapidly colonised and infected plants grew little but during the fifth week there was some recovery and shoot growth increased, although infected plants remained much smaller than controls.

The effects of *Fusarium culmorum* could not be explained by phloem disruption, which did not occur until the fourth week, whereas within one week from sowing infection had reduced K content, shoot dry weight and water content, and the dry weight of seminal roots. It is possible that a phytotoxin was involved. Production of crown roots began during the second week but initially they were infected rapidly. Most of the K and P taken up was retained in the roots and shoots grew poorly. Some recovery occurred during the fourth and fifth weeks when new uninfected crown axes were able to translocate minerals to the shoots but infected plants remained stunted. A phytotoxin may also have been responsible for the effects of *Cochliobolus sativus*. Although this fungus colonised the stele in the fifth week, it did not disrupt the phloem during the experiment or alter the distribution of photosynthetic assimilates. However during the first week infection decreased root and shoot dry weight, K uptake and shoot water content. New roots were produced and although they became infected plants generally recovered and after five weeks did not differ in dry weight from controls, although the shoot K content was less. (Fitt and Hornby)

Image analysis of aerial photographs. Aerial photographs of Rothamsted Farm were provided by the Ministry of Agriculture's Aerial Photograph Unit at Cambridge, from flights made in July 1975 and 1976. Photographs of selected experimental barley sites on black and white infra-red and black and white panchromatic film were analysed using the Quantimet 720 Image Analysing Computer.

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In an experiment on nitrogen and foliar diseases in 1975 a linear relationship was established between brightness on a black and white infra-red photograph and individual plot yields. No correlation existed between brightness and yield on black and white panchromatic photographs. Similar results were obtained in 1976, when plots treated with tridemorph fungicide to control powdery mildew were brighter and had higher yields than untreated plots. (Turner and Finney)

Diseases of grass and forage crops

Virus diseases of grasses

Barley yellow dwarf virus (BYDV). Samples were received from ADAS as part of a continued survey of viruses in ryegrass (*Rothamsted Report for 1975*, Part 1, 251). Ten samples sent from each of ten fields (five perennial and five Italian) were bulked, potted up and infested with a mixture of the possible aphid vectors *Rhopalosiphum padi*, *Macrosiphum* (*Sitobion*) *avenae* and *Metopolophium festucae*.

BYDV was isolated from all regions except the north of Scotland and most infection (70%) was found in S.E. and S.W. England. *R. padi* was the most frequent vector in all regions except S. Wales and E. Midlands and the severity of the BYDV isolates was similar in all areas. This shows that grass differs little as a reservoir of BYDV and suggests that the more frequent occurrence of severe *R. padi*-transmitted isolates of BYDV in cereals grown in the west of Britain is due to the effects of weather on aphid biology and that the potential for severe infection of cereals also exists in eastern areas. (Lennon and Plumb)

Ryegrass mosaic virus (RMV). Cutting removes most of the mite (*Abacarus hystrix*) vectors of RMV but less than six weeks after a cut in July, 15 mites per tiller occurred on unsprayed plots of perennial ryegrass cv. S.24. Plots sprayed once (endosulphan after cutting, May, June or July) bore one per tiller; those sprayed monthly had none. By October unsprayed plots contained more than 100 mites per tiller, those sprayed once 39 per tiller and those sprayed monthly one per ten tillers. Some individual tillers in unsprayed areas had more than 800 mites and showed signs of direct damage. These figures suggest a mean generation time between August and October of 2–3 weeks on unsprayed plots.

In contrast to cv. S.22 where fewer mites occurred on infected plants (*Rothamsted Report for 1975*, Part 1, 258), there was no difference in the mean numbers of mites on naturally infected cv. S.24 in October. Healthy plants bore 43 per tiller while infected plants had 52 per tiller.

An average of 19 mites per tiller occurred in September 1976 on a range of Italian and perennial cultivars sown in autumn 1975, and cut once, but the same cultivars open sown in April 1976 and uncut, bore only one per tiller. However, when undersown in spring barley there were 15 mites per tiller. We also confirmed that mites prefer the tetraploid perennial cv. Reveille, which bore almost ten times as many mites as the diploid cultivars Endura and S.24. (Plumb and Gibson)

Chemical control of mite vectors. Italian ryegrass cv. S.22 and perennial ryegrass cv. S.24 sown in May 1975 grew slowly because of dry conditions and were cut for the first time on 26 November. The worst yields were from plots that had not been sprayed with the acaricide endosulfan to control the mite vectors of RMV. Spraying in July when there was little growth and good penetration of the spray increased the yield of S.22 by 12% and S.24 by 19%. Spraying monthly from July to October, although decreasing mite numbers (*Rothamsted Report for 1975*, Part 1, 259) had no additional effect on yield.

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In spring 1976 there was little RMV in S.24 but 40% of unsprayed S.22 showed symptoms, compared with 12% when sprayed in July or monthly from July to October. S.22 yielded 10% more (mean of 2 cuts) in 1976 when sprayed monthly than when unsprayed. S.24 sprayed in July 1975 yielded 7–8% more than unsprayed.

In October 1976 24% of unsprayed S.24 was infected with RMV compared with 7% when sprayed in July or monthly. These results suggest that useful increases in yield may result from early treatment to kill mites and restrict RMV infection. (Plumb and Gibson)

Clones of perennial ryegrass resistant to RMV. The method of selecting, from within cv. S.23, two clones of perennial ryegrass resistant to a Rothamsted isolate of RMV has already been described (*Rothamsted Report for 1975*, Part 1, 258). In a subsequent test, ten isolates of RMV, obtained from naturally infected plants collected in England, Wales and Scotland, were manually inoculated to plants of each clone and to unselected S.23. All isolates produced symptoms on S.23, infecting 56 out of 100 plants, but no symptoms appeared on plants of either clone. In backtests to S.22, 126 plants were infected out o 180 inoculated from S.23, but only four and five of each 180 inoculated from the two clones. No particles were found, using electron microscopy, in the clonal plants from which infection had apparently been derived. This occasional appearance of infected plants in the backtests from inoculated plants of the two clones suggests that, although they resist a range of British RMV isolates, they are not completely immune. Plants of the two resistant clones have been planted at nine sites in Britain to test their resistance to RMV and their susceptibility to other diseases. (With Dr. A. J. Heard, Grassland Research Institute)

In the first year of a small autumn-sown experiment at Rothamsted, one of the clones yielded as much dry matter as unselected S.23, whereas the other clone yielded only half as much. In spring-sown experiments, plants of both clones often appeared less vigorous than unselected S.23 plants.

In comparison with unselected S.23 seedlings, fewer seedlings obtained from crossing the two clones became infected when sap-inoculated with the Rothamsted isolate of RMV. The progeny of resistant plants that did become infected usually took twice as long for symptoms to show, and even six weeks after inoculation less than half the tillers of infected plants had RMV symptoms whereas more than 90% of unselected S.23 had symptoms on all tillers. (Gibson)

Virus diseases of clovers

Red clover necrotic mosaic virus (RCNMV). This virus, first reported in Czechoslovakia, is known to have occurred in Britain only once, at the Grassland Research Institute in 1972. This year it was identified in all the red clover cultivars sown in 1974 and 1975 at the three Scottish Colleges of Agriculture, Edinburgh, Ayr and Aberdeen, in some at trials centres of the National Institute of Agricultural Botany at Cockle Park, Northumberland, Trawscoed, Wales and Seale Hayne, Devon as well as in scattered crops in Scotland and at Cambridge. The effects of the virus were severe and infected plants were stunted and distorted. Leaf symptoms first appear as veinal chlorosis, followed by necrosis which may affect the whole leaf. Leaves are smaller than normal and may be wrinkled. In the severest cases plants are killed.

The virus has a spherical particle 30 nm in diameter, occurs in large concentrations in sap of infected clover and produces chlorotic local lesions followed by veinal necrosis when manually inoculated to *Phaseolus vulgaris* cv. The Prince. The identity of the virus was confirmed in serological tests using an antiserum prepared in Sweden (Gerhardson & Lindsten, *Phytopathologische Zeitschrift* (1973) **76**, 67–79).

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No invertebrate vector is yet known although we have tested various aphids and weevils. The virus is readily mechanically transmitted and this may be the most important means of spread in crops. A seed stock which was used to sow plots which subsequently showed infection with RCNMV was tested for seed infection. Of 1010 seeds germinated, 6·6% showed virus-like symptoms but only 2·1% contained spherical virus particles when examined by electron microscopy. Subsequent tests by serology and inoculation to indicator plants have not shown this virus to be RCNMV. (Plumb and Bowen)

Viruses in white clover. Testing of samples from three-year-old plots of white clover at Rothamsted revealed clover yellow vein virus in 21% of plants (mean of five cultivars), cucumber mosaic virus (see below) in 3% and white clover mosaic virus in 7%. Clover yellow vein virus appeared to be distributed over the whole experimental area but was more common in some cultivars (e.g. S.184) than in others (e.g. S.100). Cucumber mosaic virus was largely restricted to the S.E. corner of the experimental area, suggesting spread from that direction, and caused over 40% infection in one plot. Red clover vein mosaic virus was not detected although in a national survey made 13 years ago this was the virus most frequently found. (Govier and Cockbain)

Cucumber mosaic virus from white clover. A virus isolated from white clover caused very small necrotic lesions on the inoculated leaves of *Chenopodium amaranticolor* but no systemic infection, and caused a systemic mottle in *Nicotiana clevelandii*. Mechanical inoculations made with sap from *N. clevelandii* or *N. tabacum* cv. Xanthi-nc infected *N. tabacum* cvs. Xanthi-nc and White Burley, cucumber and *Zinnia elegans* systemically, and *C. quinoa* and cowpea locally; tomato, French bean and two species of lupin were not infected. The virus was transmitted non-persistently by the aphid *Myzus persicae* and protected *N, tabacum* cv. Xanthi-nc against infection with a yellow strain of cucumber mosaic virus. Purified preparations reacted with an antiserum to cucumber mosaic virus in agar gel immunodiffusion tests. This appears to be the first record of natural infection of white clover with cucumber mosaic virus. Attempts to infect white clover seedlings by mechanical or aphid inoculation from *N. tabacum* cv. Xanthi-nc have so far failed. (Govier)

Pests, diseases and root mycoflora changes in maize crops at Woburn. For six years maize has been grown at Woburn in an experiment testing dazomet and levels of N fertiliser. The crops remained remarkably free from pests and diseases for the first four years and the 1975 (5th) crop had only low incidences of common smut (0·1%) and stalk rot (1·4%). In 1976, however, the incidence of smutted stalks in plots ranged from 1·2% to 11·4% (mean = 3·7%) in mid August but the treatments did not differ significantly. In the next month another 1% of stalks developed galls in most plots. On 1 July 24% of the plants in the experiment showed evidence of earlier frit fly attack; later some plants developed purple sheath blotches and in mid-September one or two fallen stalks were beginning to rot at breaks. The damage caused by common smut was probably not great and the increased incidence of the disease in 1976 probably owed more to the hot, dry summer than to monocropping.

Previous *Reports* (*for 1971, 1973, 1975*) record decreased populations of free-living nematodes and consistent increases in yields where dazomet was applied to the soil at 450 kg ha^{-1} annually in the autumn. In 1975 the root mycoflora of plants grown with and without dazomet were compared and found to differ. Early in the season *Aureobasidium bolleyi* and *Epicoccum purpurascens* were suppressed and *Trichoderma viride* aggr. was increased where dazomet had been applied. (Hornby, with Barnard, Field Experiments Section)

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Diseases of grain legumes

Soil-borne fungal diseases. Aware of the increasing interest in grain legumes and of the disease problems that might arise if legumes were grown more frequently in crop rotations, we began a study of their soil-borne disease relationships. Peas, *Vicia* beans, *Phaseolus* beans and white lupins were grown in pots of six soils that had different histories of previous *Pisum*, *Vicia* or *Phaseolus* crops. *Vicia* emerged well in almost all soils whereas pea and *Phaseolus* emerged poorly in soils cropped previously with pea or *Phaseolus*. In soil previously cropped with *Vicia* the roots of this species were severely diseased whereas the roots of pea and *Phaseolus* were healthy. Conversely, in soils previously cropped with pea or *Phaseolus* the roots of these two species were diseased whereas those of *Vicia* were comparatively healthy. Lupin behaved like pea and *Phaseolus*. *Thielaviopsis basicola* was the main pathogen on roots of pea, *Phaseolus* and lupin but *Fusarium oxysporum* and *Pythium* species were also common. *Fusarium* species and *Phytophthora megasperma* were the main pathogens in roots of *Vicia* in 'vicia' soil. *Fusarium oxysporum* and *Pythium* species were also present. Pea-cyst-eelworm and stem-eelworm were not seen. (Salt)

Virus diseases of field beans (*Vicia faba L.*). Reliable assessment of the incidence of viruses was not possible in most spring-sown crops at Rothamsted and elsewhere in 1976 because high temperatures in June suppressed virus symptoms and the drought from May onward caused severe stunting and much wilting of the leaves. *Acyrthosiphon pisum*, the main vector of bean leaf roll virus, was common in May and June and 27% of Minden plants in irrigated plots without aphicide at Rothamsted showed leaf roll symptoms early in July. By contrast, fewer than 8% of unirrigated Minden plants and 3% of unirrigated Maris Bead plants showed symptoms at this time, possibly because they were less susceptible but more likely because symptoms were suppressed. Symptoms of two other aphid-borne viruses, bean yellow mosaic and pea enation mosaic, were also relatively uncommon but both viruses were detected in a sample of plants that were without obvious symptoms at the end of flowering. Seed-borne infection with broad bean stain virus (BBSV) and Echtes Ackerbohnenmosaik-Virus (EAMV) was detected at Rothamsted in plots grown for experiments with these viruses and in one farm crop but the viruses seemed not to spread into crops grown from virus-free seed. The main vector, *Apion vorax*, was uncommon except in a small crop alongside a field cropped with field beans in 1975. (Cockbain and Bowen)

Observations on viruses and vectors in 'Factors Affecting Yield Experiments, 1st Year' are given in Field Experiments Section Report, p. 152.

Effects of insecticides on seed infection. Last year (*Rothamsted Report for 1975*, Part 1, 262) we confirmed that sprays of fenitrothion or malathion were more effective than phorate granules in checking the spread of BBSV and EAMV in plots grown from an infected seed lot. However, tests done this year on the progeny seeds showed that no treatment had significantly decreased seed infection. The proportion of seeds that produced infected seedlings when sown in a glasshouse ranged from 0·7% from plots treated with malathion or fenitrothion and phorate to 2·2% from plots treated with phorate alone; the proportion from untreated plots was 1·7%. This was possibly because BBSV and EAMV are transmitted most often through seeds set by plants that are infected early in development and possibly the insecticides were applied too late (most seedlings had emerged by 12 May but insecticides were not applied until 22 May) or were not sufficiently effective to check early spread. Furthermore, plants infected through the seed were not removed and presumably produced some infected seeds.

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This year an experiment was done to assess the effects of roguing on seed infection in plots treated with fenitrothion (applied three times at 0·74 kg a.i.ha^{-1}) or fenitrothion and phorate (3 × 1·0 kg). Two seed lots were sown, one with 0·3% of seeds infected and the other with 1%, and plants showing symptoms of BBSV or EAMV were removed from half the plots five times between 21 April (1–2 weeks after emergence) and 17 June (late flowering). *A. vorax* was uncommon and only 1% of plants in unrogued plots sown with the low infection seed and 2% with the high infection seed showed obvious symptoms of BBSV or EAMV as the beans came into flower. Seeds from this experiment will be tested for infection in 1977. (Cockbain and Bowen, with Etheridge, Insecticides and Fungicides Department)

Persistence of BBSV and EAMV in seed. Seeds stored for four years at 15°C produced as many seedlings infected with BBSV or EAMV as had a sample from the same seed lot that was germinated a few weeks after harvest. Possibly, like some other seed-borne viruses, BBSV and EAMV persist in seeds for as long as the seeds remain viable. (Cockbain and Bowen)

Viruses of dry beans (*Phaseolus vulgaris* L.). The seed and aphid-borne bean common mosaic virus and the aphid-borne yellow mosaic virus were isolated from several varieties of *P. vulgaris* at Woburn (see Soil Microbiology Department Report, p. 288). Symptoms in different cultivars ranged from a mild chlorosis to severe leaf mosaic, leaf malformation and dwarfing of the plants. In late July the proportion of plants with obvious symptoms ranged from 0·4% in plots of cvs. Redkloud and Tendergreen to 50–60% in plots of cvs. Linea 17 and Pompadour 2 (mean for all cultivars, 17%). Plants of cvs. Purley King and S-166-A-N that showed symptoms yielded, respectively, 27 and 32% fewer pods and 24 and 30% less seed than plants without symptoms. (Cockbain and Bowen)

Pests and diseases of grain lupins. Details of treatments and yields in plot experiments with *Lupinus albus* (Kievsky mutant) at Rothamsted and Woburn are given in the Report of Field Experiments Section, p. 155.

Poor germination and damage by birds resulted in a much sparser stand of *L. albus* at Rothamsted (22 plants per 5 m row) than at Woburn (61 per 5 m row) and the plots at Rothamsted, particularly those without aldicarb, were damaged more by weevils (*Sitona* spp.). At both sites aphids (mainly *Brachycaudus helichrysi* and *Macrosiphum euphorbiae*) were less common than at Rothamsted in 1975 and fewer plants were infected before flowering with the aphid-borne bean yellow mosaic and clover yellow vein viruses.

In July it was again difficult to distinguish wilt symptoms caused by clover yellow vein virus, *Fusarium oxysporum* and drought. The roots of wilted plants usually looked healthy but a red-brown vascular discoloration was frequently found when the tap-root was split longitudinally. From these plants both clover yellow vein virus and *F. oxysporum* were usually isolated. Lupins that wilted in pots after inoculation with virus exhibited no vascular symptoms. (Cockbain, Bowen and Salt)

Diseases of *Brassica* crops

Incidence of diseases of winter oilseed rape (*Brassica napus* ssp. *oleifera*) in 1976. The incidence of foliar diseases was recorded on samples of 50 plants, taken in late May–early June, from crops of cvs. Primor, Rapora, Expanda and Victor on 12 sites in Hertfordshire and Bedfordshire near to the sites surveyed in 1975 (*Rothamsted Report for 1975*, Part 1, 264).

Light leaf spot or leaf scorch (*Pyrenopeziza brassicae* imperfect state *Cylindrosporium*

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concentricum) was recorded on 20% of all plants examined, downy mildew (*Peronospora parasitica*) on 36% and *Botrytis cinerea* on 10%. The lower incidence of leaf scorch and downy mildew compared with that recorded in 1975 (41 and 57% respectively) doubtless reflects the much drier weather this year. However, even in the absence of much rain-splash dispersal, which is presumed to be important for the spread of *Pyrenopeziza*, its incidence on some sites was surprisingly high, e.g. 58% in a commercial crop of cv. Primor. There was much variation in incidence on different cultivars, most (60%) being recorded on an experimental, third consecutive crop of cv. Victor (a cultivar hitherto regarded as relatively resistant to leaf scorch) at Rothamsted and least (2%) on cv. Rapora. Variation in incidence on the same cultivar grown at different sites was also marked, e.g. 8–58% on cv. Primor. The high incidence at some sites shows that inoculum can persist and the disease continue to develop even during a year of severe drought, suggesting that it could quickly become a serious problem again during a wet season.

Incidence and severity of leaf scorch at the rosette stage (February) were unreliable as a basis for forecasting. Grazing by pigeons was severe in the early part of the year and, coupled with the exceptional drought and weed infestation, spoiled one of our experiments completely.

Effects of herbicides on disease. Records taken from crops growing in ADAS Eastern Region weed control trial sites confirmed last year's experience that most leaf scorch was associated with the use of herbicides containing dalapon and least with those containing carbetamide. Scanning electron micrographs of leaves taken from these sites in February, at least three months after the application of herbicide sprays, clearly showed less cuticular wax on leaves treated with dalapon compared with those given propyzamide or carbetamide. Similarly, leaves of plants grown under simulated autumn conditions of temperature, humidity and light intensity, examined two months after the application of dalapon (3 kg ha^{-1} equivalent), and therefore affected only by translocated herbicide, were up to 66% more wettable and had up to 55% less wax by weight per unit leaf area than unsprayed plants. The methods used to measure wettability and wax were those of A. M. S. Silva Fernandes (*Annals of Applied Biology* (1965), **56,** 297–304).

Studies on *Pyrenopeziza brassicae*. Experiments on cvs. Eurora and Primor showed that spores applied to leaves in water droplets deposit over the anticlinal walls of epidermal cells. Under simulated autumn conditions (5–8°C, high humidity, low light) they can complete a cycle from penetration to sporulation in one month, although the process usually requires longer. Only a small proportion of spores applied to leaves germinated quickly; most remained ungerminated for at least three months. Leaves treated before inoculation with either a non-ionic surfactant or dalapon, or subjected to mechanical damage, all developed more pustules than untreated leaves. Most efficient inoculation was achieved by a spore suspension applied under partial vacuum to seeds about to germinate. On leaves, inoculation using spores was more effective than discs of agar with mycelium, and drops of spore suspension confined within small plastic domes secured to the leaf with lanolin were more effective than unprotected drops, suggesting that free water rather than high humidity alone is required for optimum infection. Spores produced very little superficial mycelium over the surface of the cuticle; germ tubes up to three times the length of the spore produced small appressoria, penetrated the cuticle and produced long 'runner' hyphae under the cuticle before forming 'plate mycelium' and acervuli which later break through the cuticle to sporulate. Infection hyphae penetrated between the anticlinal walls of epidermal cells but never through cell walls. Initial penetration was not through stomata or related to the vein structure of leaves and, as in the field, disease symptoms and areas of sporulation were distributed according to drip

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patterns on leaves. Some leaves curled naturally at their tips forming depressions which held run-off water, and in others the tips of lobed leaves had sunken stomata and fewer rodlets of wax than surrounding areas of the lamina. These features might dispose leaves to infection.

A comparison of all methods of treating and inoculating leaves indicated that cv. Primor was naturally more resistant to infection than cv. Eurora. (Rawlinson, Muthyalu and Turner)

Clubroot (*Plasmodiophora brassicae*). The experiments on effects of systemic fungicides and growth regulators on clubroot of cabbage were continued, many compounds being tested including most of those tried last year (see Report, Insecticides and Fungicides Department, p. 178). DL-ethionine (0·5% sprays) sometimes increased the weight of tops though not to equal that of uninoculated controls. More often, the weight of clubs was decreased, especially when plants were sprayed two to three weeks after inoculation. (Macfarlane, with McIntosh, Insecticides and Fungicides Department)

Potato diseases

Last season was considered 'exceptionally difficult' for the potato crop but this season nearly proved disastrous. Soil conditions were ideal for early planting and strong emergence, but lack of rain soon put crops under stress and, apart from one period of 16 mm in June and one of 36 mm in July, there was no rain of consequence from planting until early September. Soil temperatures at tuberising depth often exceeded 20°C for 12 h or more from mid-June until late August and during late June until mid-July sometimes exceeded 24°C for 15 h or more.

Unirrigated Pentland Crown withstood these conditions well (yield 35 t ha^{-1}) but King Edward was particularly affected. Yields were low (24 t ha^{-1}), tubers small and often badly damaged by cutworms. Stolons developed from the apex of some tubers to form another generation of tubers (chain tuberisation) or, late in the season, aerial shoots. First-formed tubers in the chain became rubbery, glassy and inedible, or degenerated. From September soils became increasingly wet and lifting was difficult and inefficient in muddy conditions on some plots. Tubers not harvested could establish large groundkeeper populations, although this could be mitigated by the frosts experienced in December, which were severe enough to freeze up to 50% of tubers in plots that had not been harvested.

Bacterial soft rot

***Underground spread of* Erwinia carotovora *var.* atroseptica.** The main source of inoculum for contaminating progeny tubers is considered to be the disintegrating seed (mother) tubers, which rot at different times during the growth of the potato crop. To simulate degeneration at different times, partially spent mother tubers (recovered from a growing crop) were inoculated with a serologically specific strain of var. *atroseptica* and placed by the side of seed tubers of plants in the field at monthly intervals from June to September. Plants were dug two, four and eight weeks after placement and at a final harvest and the progeny tubers assessed for bacterial contamination to determine when most bacterial spread would have occurred in 1976 and how long rotting tubers remain an inoculum source. The first spread to be confirmed was on 7 September in the eight week sample of the July and four week sample of the August placement, which coincided with the end of the prolonged hot dry weather. Spread was also detected in the two week and seven week (final harvest) samples of the September placements. Although progeny tubers from the June placement did not become contaminated during the first eight weeks, spread had

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occurred by final harvest (20 week) when the serologically specific strain of var. *atroseptica* could still be isolated from the remains of the placement tubers and from soil immediately surrounding them. (Harris and Lapwood)

Gangrene (*Phoma exigua* var. *foveata*)

Detection of the pathogen in soil. In several experiments, slices of Arran Banner tubers, which have been used in testing field soils for natural infectivity, were inoculated with soils containing known concentrations of pycnidiospores. Slices appeared to increase in susceptibility with increasing time of storage of the test tubers and were generally more susceptible than in 1974. Concentrations of less than 10^2 spores g^{-1} were readily detected, despite occasional latent infection of the test tubers, compared with existing agar plate methods which will just detect 10^3 spores g^{-1} soil. A comparison between the tuber-wounding test and the potato slice test showed the latter was more sensitive when populations of the pathogen were small.

Survival in soil. Non-sterile loam inoculated with pycnidiospores was stored at 5, 10 and 15°C. When tested on Arran Banner slices more than a year after inoculation, the pathogen was no longer detectable in the soil stored at 15°C, populations at 10° were small, but at 5° were still large. Inoculated soil placed in 15 cm long glass tubes, buried to the rim in the field in February 1976, still had detectable populations of the pathogen, using both agar plate and Arran Banner slice methods, in October, after an exceptionally hot, dry summer. Other experiments showed that populations declined much more rapidly in soils held at field capacity than in those at *c.* 75% field capacity or air-dried.

Tuber maturity, wound healing and susceptibility. In 1974 and 1975, King Edward tubers were lifted on various dates between early September and mid-November, given wounds of uniform depth and cured for periods of up to 21 days at 15°C. Wounds were inoculated either before or after curing and gangrene development assessed after a period of cold storage. When inoculated after seven days' curing very few wounds on tubers of any harvest date became infected. Inoculation of wounds before curing, or after three days' curing indicated that the later tubers were harvested, the more susceptible were their wounds and the more slowly they cured. These and other results at Rothamsted indicate that crops burnt off and lifted early should develop less disease in store. (Adams)

Effects of *Verticillium dahliae* and *Globodera rostochiensis* interaction. In earlier experiments death of haulm caused by *V. dahliae* and *G. rostochiensis* was delayed and yields greatly increased by treating soil before planting with methyl bromide, aldicarb or benomyl. In 1976, plots untreated or fumigated with methyl bromide at 196 or 975 kg ha^{-1} were planted with Pentland Dell or Pentland Crown seed. Plant emergence, haulm senescence and ground cover were recorded weekly and plants were sampled on five dates at three-week intervals to measure leaf area and yield. Methyl bromide at 975 kg ha^{-1} delayed emergence and early growth of both cultivars but these phytotoxic effects had disappeared by mid-July. Tuber production and bulking were also delayed especially in Pentland Dell. In both cultivars methyl bromide at both rates increased plant height by 30% and doubled yield in mid-September.

On all dates leaf area of Pentland Crown plants was less in untreated than treated plots but haulm appearance was similar until mid-August when plants in untreated plots senesced; yields from untreated plots were not less than from treated plots until mid-September, the two rates being equal in all these respects. Pentland Dell in untreated plots showed symptoms of haulm senescence at the beginning of July, tuber bulking was

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slow and plants were dead in mid-August. Methyl bromide increased leaf area, delayed haulm senescence and in mid-September increased tuber numbers and yield especially at the higher rate. (Hide, with Evans, Nematology Department)

Potato and red beet scab (*Streptomyces* sp.). Potatoes growing in scab-infested soil at Woburn were watered (to prevent scab) or not and samples of developing tubers were examined during the first week of June to determine the effects of watering on the microflora of the tuber surface. Examination of tuber periderm by scanning electron and by light microscopy demonstrated the scarcity of actinomycetes and bacteria on the second internode from the apex of a growing tuber. On older tissue from dry soil there was extensive colonisation by actinomycetes and bacteria were present in discrete colonies. Tissue from wet soil had less actinomycete growth and bacteria were more generally distributed. (Adams and Lapwood)

In a pot experiment, red beet plants were inoculated with a pathogenic isolate of *Streptomyces* at the susceptible decortication stage and sprayed with daminozide and DL-ethionine at three concentrations on one of three dates. On unsprayed controls and on plants sprayed 11 days before or nine days after inoculation, about 33% of the beet surface area became scabbed but when DL-ethionine was applied one day before inoculation at concentrations of 0·5 or 1·0%, the scabbed area was decreased to 13 and 8% respectively. (Adams and Lapwood, with McIntosh, Insecticides and Fungicides Department)

The use of fungicides against tuber pathogens

Treatment of ware tubers. On a farm near Oxford, 'Storite' (60% thiabendazole) sprayed on to tubers was compared with thiabendazole applied as a smoke for disease control. After treatment, 30 and 17% respectively of the thiabendazole applied was recovered from unwashed tubers. However, amounts of thiabendazole recovered from unwashed tubers are dependent on the amount and type of adhering soil. After five months samples of tubers were washed, examined for diseases and analysed for residues. With both methods of application, 12% of the thiabendazole applied was recovered. Skin spot was prevalent on the untreated tubers and especially on scuffing damage but the disease was decreased ten-fold by both treatments. The smoke was less effective than the spray in decreasing silver scurf.

In collaboration with the Potato Marketing Board, experiments at Sutton Bridge Experimental Station compared thiabendazole applied as a fog or smoke to tubers in bulk and as sprays to tubers before storage in boxes. Sample nets were distributed through 30-t bulk stores at different heights and fungicides (thiabendazole smoke tablets; thiabendazole + chlorine fog, 'Tubazole' (thiabendazole fog)) were introduced through ventilation ducts. Amounts of thiabendazole in washed tubers after storage indicated a fairly uniform lateral spread of fungicide but a decrease from the floor to the top of the stack, with *c.* four times as much fungicide at all levels from smokes compared with fogs. All treatments decreased silver scurf equally whereas skin spot was decreased by thiabendazole smoke and thiabendazole + chlorine fog but not by 'Tubazole'. Both diseases were least prevalent in the lower part of the bulk where amounts of thiabendazole on tubers were highest.

Tubers stored in 1-t boxes were sprayed at loading with 'Storite' or thiabendazole + chlorine and some replicates treated with tecnazene or chlorpropham to suppress sprouting. In all treatments *c.* 9% of thiabendazole applied was recovered from washed tubers. Skin spot was decreased by 'Storite' and more by thiabendazole + chlorine; it was further decreased by tecnazene but slightly increased by chlorpropham with both formu-

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lations. Silver scurf was decreased equally by the thiabendazole formulations and was unaffected by either sprout suppressant.

Unfortunately gangrene, the main reason for using these fungicides, was not prevalent in any of the experiments. (Hide, with Austin, Cayley, Davies and Lord, Chemical Liaison Unit)

Treatment of seed tubers. Seed of four cultivars derived either from tuber selections (FS certificate) or from stem cuttings (VTSC) was treated with 2-aminobutane or with benomyl or thiabendazole and grown at Rothamsted and Woburn in 1973, 74 and 75. Seed derived from stem cuttings had slightly more stems (5.4 per plant) than FS (4·6) at both sites and at Rothamsted yielded 7% more (5% ware). Fungicides had no significant effect on the incidence of gangrene which was lower in plots from VTSC than FS only at Rothamsted in 1975. *Polyscytalum* on tuber eyes after lifting in 1973 and 1974 was decreased by more than 80% by seed treatment with benomyl or thiabendazole and in 1975 the number of tubers with skin spot after four months storage was decreased by 50%. The disease was unaffected by seed treatment with 2-aminobutane. Similarly, seed treatment with benomyl or thiabendazole decreased the incidence of *Helminthosporium* on tuber skin after lifting by 75% and in 1975 silver scurf was least prevalent in these treatments. The disease was seldom decreased and in more than half the comparisons increased by 2-aminobutane seed treatment. All fungicide treatments decreased *Rhizoctonia*. (Hide, Adams and Bell)

Uptake and distribution of thiabendazole in potato shoots and tubers. Thiabendazole was taken up into roots, stems and leaves when applied to cuttings before rooting, mixed with rooting medium, incorporated in the compost used for final potting, drenched onto soil or sprayed onto plants (*Rothamsted Report for 1975*, Part 1, 271). It was found in the flesh and skin of tubers, however, only when mixed with the potting compost.

In 1976 stem cuttings treated with thiabendazole by standing them in solutions containing 0·01, 0·1 and 1·0 ppm thiabendazole for 27 days all developed lesions when inoculated with *Phoma exigua* var. *foveata* on the fourth day of treatment. Cuttings treated at 10 ppm for 27 days or transferred to water on the fourth day immediately after inoculation did not become infected. Autoclaved stem segments plated onto malt extract agar inhibited the growth of *P. exigua* var. *foveata* only from shoots treated with 10 ppm thiabendazole solution.

Rooted cuttings grown in peat/sand compost containing 1, 10, 50 or 100 ppm thiabendazole and stem-inoculated with *P. exigua* var. *foveata* developed lesions in all treatments. Amounts of thiabendazole in stems were lower than in shoots held in solutions of similar concentration suggesting that much of the fungicide in the compost was unavailable to the plants. Thiabendazole was also found in tubers and aerial tubers.

To investigate the conditions under which thiabendazole is translocated to tuber flesh, stolon tips, tuber initials and small tubers attached to plants in pots were treated with thiabendazole solutions. In contrast to detached tubers similarly treated, in which fungicide failed to penetrate beneath the skin, (*Rothamsted Report for 1975*, Part 1, 271) fungicide was taken up into the flesh of the young attached tuber. In other tests thiabendazole was found to be taken up into tuber flesh when the stolons of freshly lifted tubers were held in fungicide solution. (Hide, with Cayley, Chemical Liaison Unit)

Survey of diseases of seed tubers. Gangrene was less prevalent in King Edward (KE) seed in 1975–76 (Table 4) than in the previous year and fewer tubers developed the disease after uniform wounding (17%). Skin spot, dry rot and powdery scab were also less common but black scurf more common. Gangrene was more prevalent in Pentland Crown (PC) than in 1974–75.

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TABLE 4

Survey of fungal diseases of seed tubers (percentage of tubers infected/percentage of stocks with infected tubers)

Examined		King Edward	Pentland Crown
R	Skin spot (*Polyscytalum pustulans*)	45/96	24/90
P	Gangrene (*Phoma exigua*)	5/51	8/65
P	Dry rot (*Fusarium* spp.)	1/31	3/33
R	Blight (*Phytophthora infestans*)	1/31	<1/10
R	Black scurf (*Rhizoctonia solani*)	42/98	34/98
R	Powdery scab (*Spongospora subterranea*)	13/78	3/37
R	Common scab (*Streptomyces scabies*)	30/92	12/90
	No. of stocks examined	49	51
	No. of potatoes examined in each stock on each occasion	50	50

R = examined at receipt; P = examined at planting

About one third of the samples received were from stocks known to be derived from stem cuttings (FS 1–4 certificate) and the remainder from tuber selections (certified or once grown). Average incidence of gangrene, skin spot, silver scurf and black scurf was similar in seed from both sources, confirming the need for measures to prevent the increase in disease during multiplication from stem cuttings. (Hide and Bell)

TABLE 5

Survey of E. carotovora *var.* atroseptica *contamination of seed tubers (No. stocks confirmed contaminated/No. stocks tested)*

	King Edward	Pentland Crown
FS 1–3	13/16	13/14
FS	1/2	1/1
AA	17/27	19/23
CC	0/1	2/2
Once grown	2/3	10/12

This year we were able for the first time to monitor all 100 stocks in the seed survey for bacterial contamination. Most tubers from all stocks could be induced to rot by submersion in water for six days and, irrespective of stock certification, *Erwinia carotovora* var. *atroseptica* was frequently isolated from them (Table 5) identified by gel double-diffusion serology (Vruggink & Maas Geesteranus *Potato Research* (1975) **18,** 546–555).

To see if frequency of blackleg symptom expression was related to the tuber contamination level 30 KE and 30 PC (ten each with above, average and below average tuber contamination) were grown in plastic bags of soil sunk into the field. Despite flooding the bags in June (a reliable technique in the past) no blackleg symptoms developed probably because of the unusually hot, dry weather. (Lapwood and Harris)

To determine if the numbers of seed tubers rotting by mid-July were related to seed stock, 25 tubers from each of 96 stocks (48 KE and 48 PC) were planted in the field. When harvested the proportion of KE seed rotting (*c.* 16%) was similar for each certification class but for PC, *c.* 20% for FS or AA and *c.* 30% for lower grades. Overall, about 12% PC and 4% KE seed tubers were reduced to skin or were not recoverable and a further 6% for each cultivar showed wet disintegrating bacterial rots from which isolations were made. *Erwinia* spp. were identified in 33% of isolations from KE and in 50% from PC. The numbers of mother tubers soft rotting in July bore no relation to the level of *Erwinia* contamination of seed found by laboratory tests.

Gangrene lesions were found on 4% KE and 6% PC seed tubers and *Phoma* was successfully isolated from 50% PC and 25% KE of rots sampled. (Lapwood, Harris and Adams)

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Forecasting storage diseases. At the invitation of ADAS, Cambridge, we sampled 12 crops on farms in Beds., Herts. and Cambs. in August and at harvest 1975, to forecast storage disease potential. After harvest, crops were stored on farms and samples were also stored at the Potato Marketing Board Experimental Station at Sutton Bridge, Lincs. Disease levels (expressed in five categories relative to the mean for all farms) in farm and Sutton Bridge stores usually agreed well; success in forecasting varied. Black scurf and skin spot were correctly forecast for ten farms, assessments made in August being as valid as those at harvest. Harvest samples gave a better indication for silver scurf but forecasts were correct for only seven farms. Gangrene and soft rot assessments in August or at harvest bore little relation to the amount of disease in store; gangrene levels after storage were better related to damage at lifting. Good lifting and storage conditions probably had a greater effect on soft rot (which was rare in all stores) than amount of inoculum on and in tubers. (Lapwood, Hide, Adams, Harris and Bell)

Potato groundkeepers. Fields in the seven-course rotation at Rothamsted were surveyed for groundkeepers in July and August. Most (16 000 ha^{-1}) were found where there were large populations in 1975 (Whitehorse 2) and the most persistent were on Gt. Knott 2 where potatoes were last grown in 1970 although no potato plants were seen in 1975. Groundkeepers were also found in plots on both ley-arable experiments (Highfield, Fosters), in wheat since the potato crop in 1966. Stem bases had severe infections of *Polyscytalum* and *Rhizoctonia* and tubers were infected with these and with *Helminthosporium*. Numbers of groundkeepers were apparently not affected by the cropping history prior to the potato crop nor by the amount of nitrogen applied to the wheat. (Hide, Bell and Lapwood)

Potato virus diseases at Rothamsted. Our own King Edward seed was rejected when the parent crop was found to be extensively virus-infected in 1975, so the 1976 experiments were planted with King Edward seed direct from Scotland and with Pentland Crown seed grown at Rothamsted in 1975. When counts were made in late June each had 0·5% leaf roll and the King Edward had 0·2% potato virus Y (PVY). PVY was not detected in Pentland Crown. Aphids were numerous and much PVY spread to King Edward from other more heavily infected sources during the season so that by mid-August many plots were showing almost 100% infection. Even crops grown in isolation to provide seed for 1977 suffered early and extensive aphid attack. Although phorate granules were applied at planting and the crop was sprayed with 'Metasystox' on 6 June, large populations of apterous aphids were found on the plants on 15 June. Tests showed that all the apterae and more than half the alatae were resistant to organophosphorus insecticides. By mid-August more than 30% of the King Edward plants were infected with PVY and the crop was rejected as a source of seed. The resistance of Pentland Crown to PVY limited infection in the seed crop to 0·1%. (Govier)

Staff and visiting workers

G. A. Salt relinquished his duties as Acting Head of Department on 1 February, when E. Lester succeeded J. M. Hirst as Head. Catherine Martin and Janet Smith resigned and Mrs. Patricia Parkins and P. J. Read were appointed during the year. Dr. Claude Ricaud, Mauritius, spent a month in the Department and Beverley Jagger, Barbara Mawby, J. Bater, R. Heath and P. Joyce worked April–September as sandwich course students.

N. White was awarded an ARC studentship for work on barley mildew and B. D. L. Fitt continued as an ARC student. R. A. Hill and P. T. Gans continued with the support of the Home-Grown Cereals Authority and the Potato Marketing Board respectively,

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the latter organisation also continuing its support of R. I. Harris in a research post. Dr. P. H. Gregory continued working at the invitation of the Lawes Agricultural Trust and organised a very successful Cocoa Phytophthora Workshop at Rothamsted in May on behalf of the Cocoa Chocolate and Confectionery Alliance.

S. J. Eden-Green continued his work in Jamaica on lethal yellowing and A. J. Dabek his work on virus diseases of taro at Rothamsted for the Ministry of Overseas Development.

R. W. Gibson is spending eight months in Peru at the International Potato Centre studying insect-trapping hairs of *Solanum* spp. as a means of biological control of insects, including virus vectors.

J. F. Jenkyn attended the 12th Colloquium of the International Potash Institute on Fertiliser Use and Plant Health, held in Izmir, Turkey, 9–15 May 1976 and presented a paper entitled '*Nitrogen and leaf diseases of spring barley*'.

J. Lacey participated in a workshop on antigens in hypersensitivity pneumonitis in Washington, USA, at the invitation of the National Institute of Allergy and Infectious Diseases and visited institutes in Wisconsin, Minnesota, Illinois and Louisiana concerned with these diseases and with problems of fodder biodeterioration.

J. Lacey also presented papers at an International Symposium on *Streptomyces* and *Nocardia* in Warsaw, Poland, and visited the National Institute of Occupational Medicine to lecture at the invitation of the Polish Ministry of Health. Institutes at Szczecin, Poland, and Vysne Hagy, Czechoslovakia were also visited.

E. Lester attended the 28th International Symposium on Crop Protection at Gent, Belgium, to deliver the plenary lecture on Plant Pathology and Plant Protection.

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